



IDEA

(Integrating Dynamics in Earth's Atmosphere)

Connecting Weather and Space Weather

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Space Weather Prediction Testbed

1. And Univ. Colorado CIRES

Outline:
Why IDEA?
What's the big IDEA?
Who's IDEA was it?
How good is this IDEA?
What Next?

Why is IDEA a Good Idea?

Multi-Day Ionospheric Forecasts

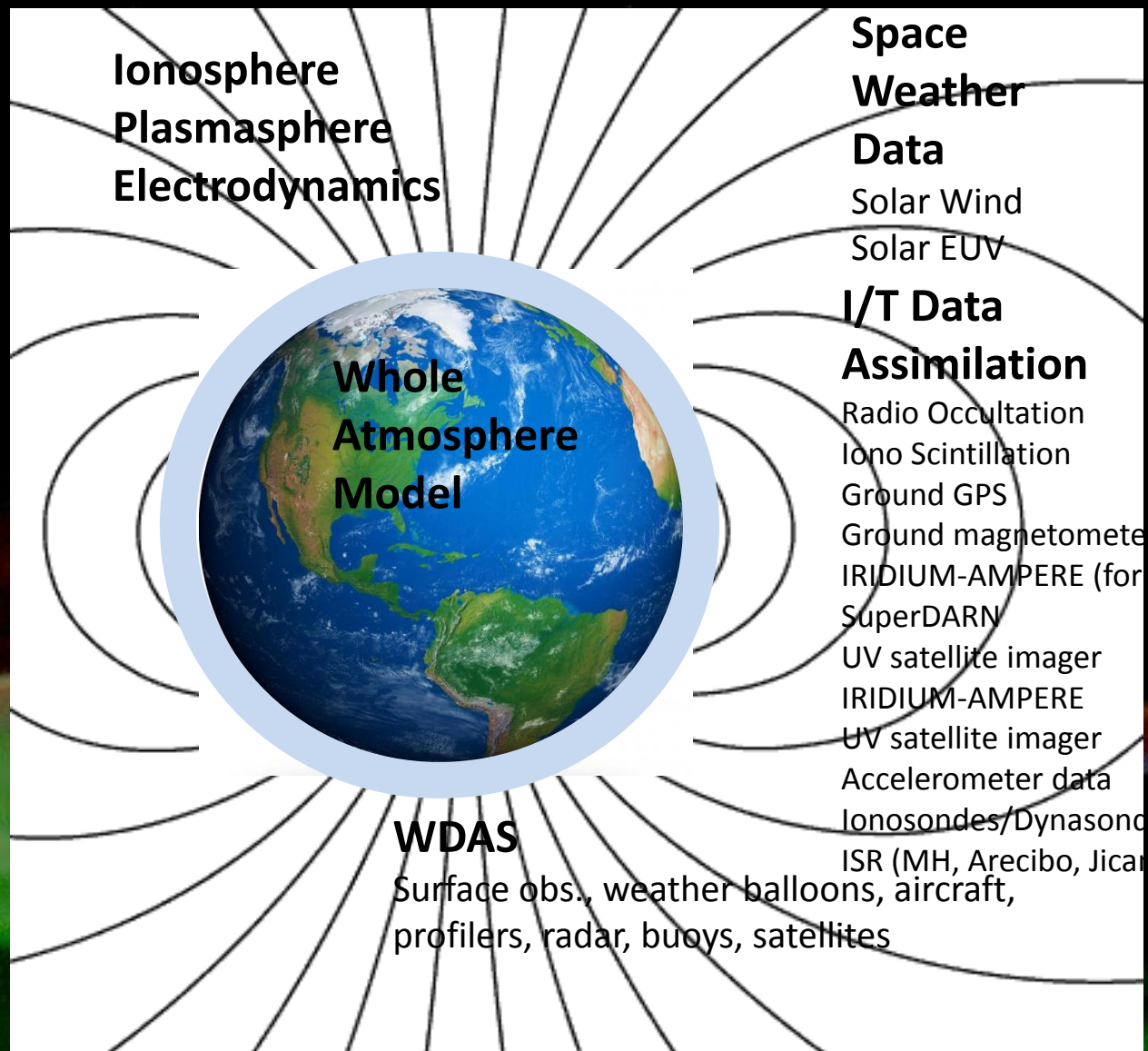
- IDEA is driven by customer requirements for better forecasting of space weather impacts on systems.
 - GPS/GNSS systems are affected by small and medium scale structures in the ionosphere that are not captured in current ionosphere models.
 - Satellite Communication (Ground to space) is affected by small and medium scale structures
 - Satellite drag is affected by medium scale structures and winds in the thermosphere (neutral atmosphere) that are not currently modeled.

How will IDEA meet the Customer Requirements?

- The Ionosphere/Thermosphere (I/T) system is a strongly driven system.
 - Most of the variability is the result of external forcing
- There are three primary external forces or drivers.
 1. Solar x-ray and EUV irradiance
 - Induces global variability of factors of 0.2 to 10 on times scales of minutes to years
 2. Geomagnetic storms
 - Induces regional variability of factors of 0.1 to 10 on time scales of minutes to hours
 3. Tropospheric variability
 - Induces local variability of 0.1 to 3 on time scales of minutes to hours.
- Nearly all I/T models capture the first two drivers but not the third.
- Specification and forecasting each of the three drivers is critical to developing an accurate forecast of the I/T system
- Only a coupled atmosphere-ionosphere model will provide adequate forecasts of space weather impacts on the systems communication and navigation systems.

What's the big IDEA?

- WAM = Whole Atmosphere Model
- (0 – 600 km)
- IPE = Ionosphere Plasmasphere Electrodynamics Model (100 – 10000 km)
- WDAS = WAM Data assimilation System (0 – 100 km)
- IDEA = WAM + IPE + WDAS
A coupled modeling system spanning from the 0 to 10,000 km



Model Development in the Thermosphere-Ionosphere: Integrated Dynamics in Earth's Atmosphere (IDEA)

Whole Atmosphere Model (WAM = Extended GFS)

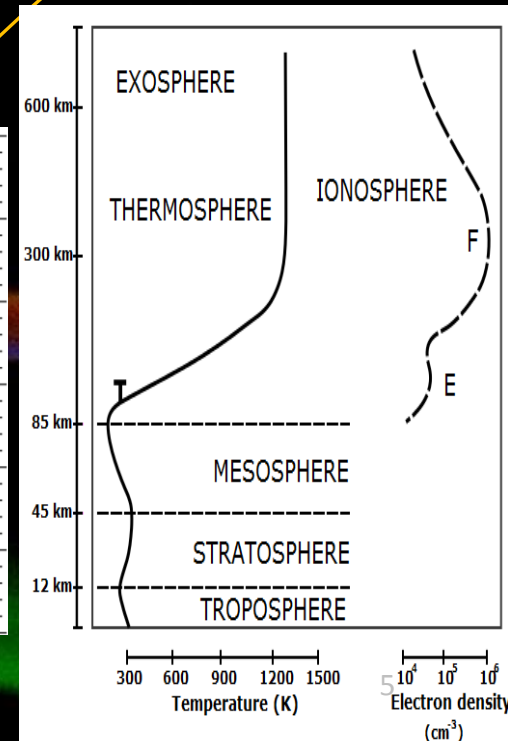
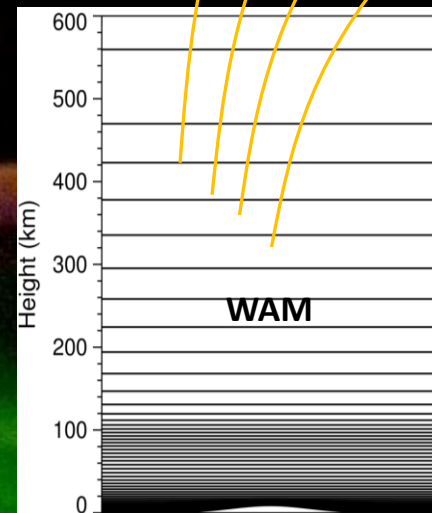
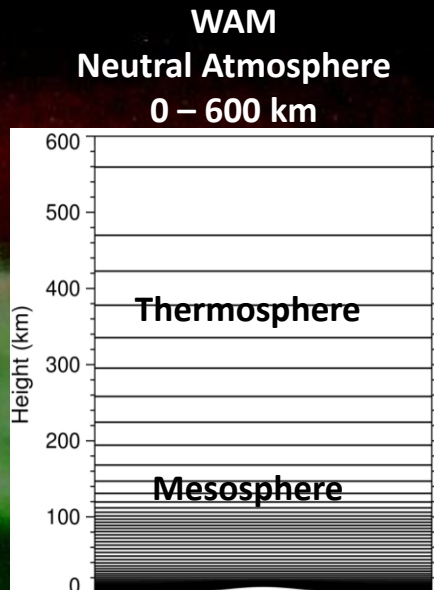
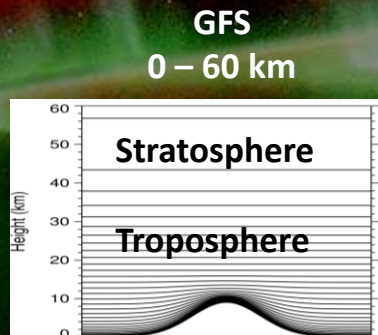
Ionosphere Plasmasphere Electrodynamics (IPE)

Integrated Dynamics in Earth's Atmosphere (IDEA = WAM+IPE)

- History:

- Research development started in 2004 with NASA, NSF, DOD funding
- Focus shifts to operational implementation in 2011
- FY15 Deliverable: Execute Real-time run of WAM on NOAA WCOSS

Ionosphere
Model



WDAS Data List

(WDAS = WAM Data Assimilation System)

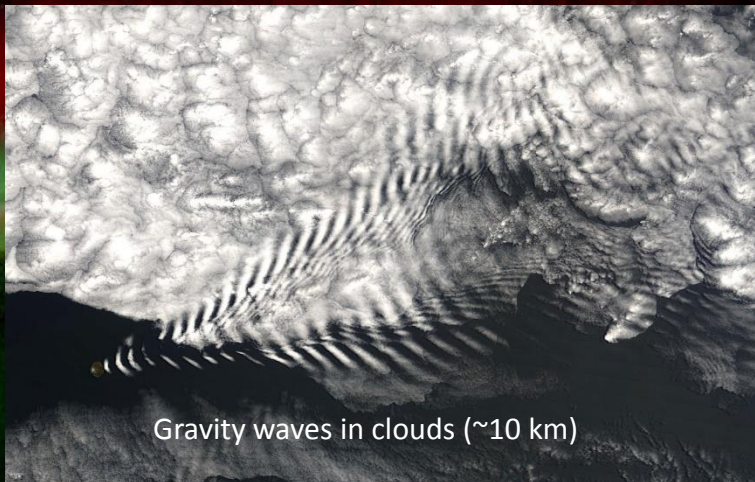
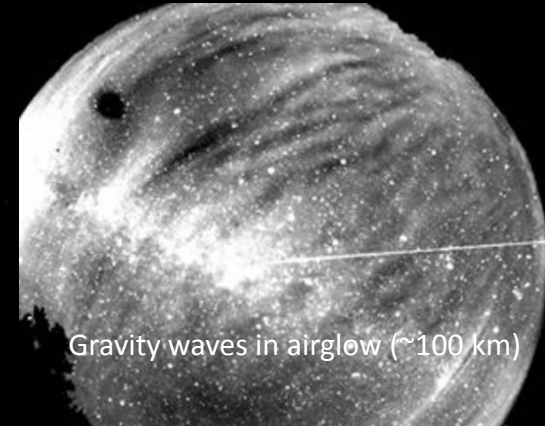
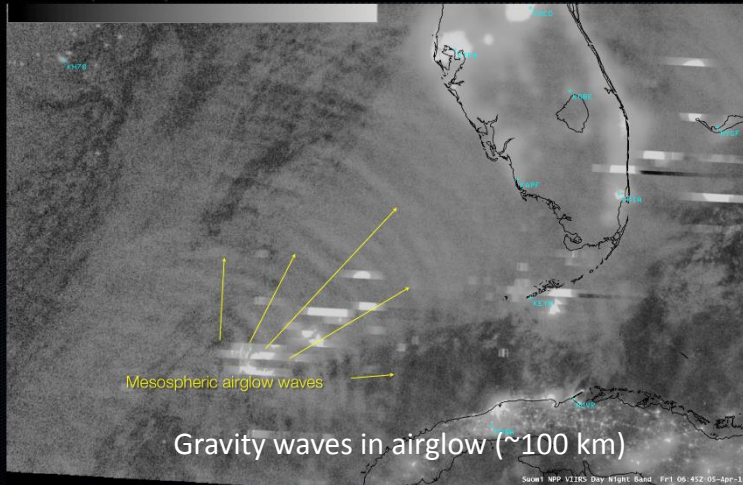
- Neutral Atmosphere (Stratosphere, Mesosphere, Lower Thermosphere)
 - Add analysis of additional channels to SSMIS to ~80-100 km altitude for temperature.
 - Extend use of AIRS, IASI, CRIS, AMSUA for temperature.
 - MLS for ozone and temperature to 85 km
- Upper Thermosphere and Ionosphere
 - Ionospheric radio occultation e.g., COSMIC-II (LOS TEC, S4, σ_ϕ)
 - Ground-based dual frequency GPS receivers
 - Ground-based magnetometers for AMIE at high latitude and vertical drift at low latitude
 - IRIDIUM-AMPERE (for AMIE)
 - SuperDARN for AMIE
 - UV satellite imager for O/N2 and/or high latitude and vertical drift at low latitude
 - IRIDIUM-AMPERE (for AMIE)
 - SuperDARN for AMIE
 - UV satellite imager for O/N2 and/or temperature e.g., GOLD
 - Accelerometer data for neutral density e.g., GOCE, GRACE, SWARM
 - Global network of Ionosondes/Dynasondes
 - ISR (MH, Arecibo, Jicamarca, AMISR, etc.)
- ACE solar wind data at L1
- Solar flux, GOES-EUV

Why Couple to the Lower Atmosphere?

1. Gravity Waves

Gravity waves

- Created by storms and mountains.
- Propagate upward.
- Grow in amplitude as they go up.
- Often break at some altitude.
- When the break, they deposit energy (both thermal and momentum).



16 April, 2015

Space Weather Workshop

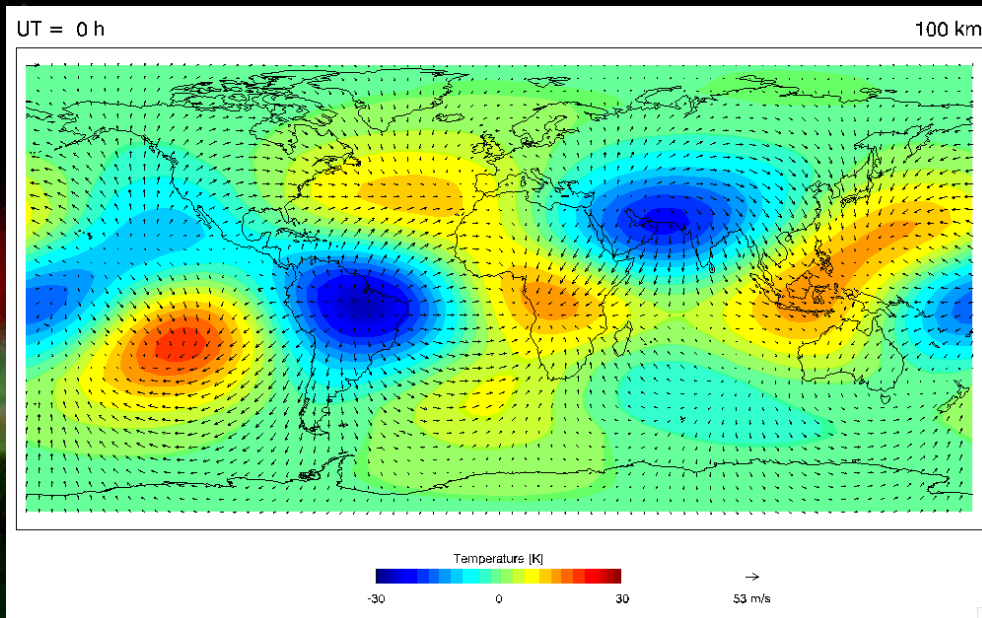
Why Couple to the Lower Atmosphere?

2. Atmospheric Tides

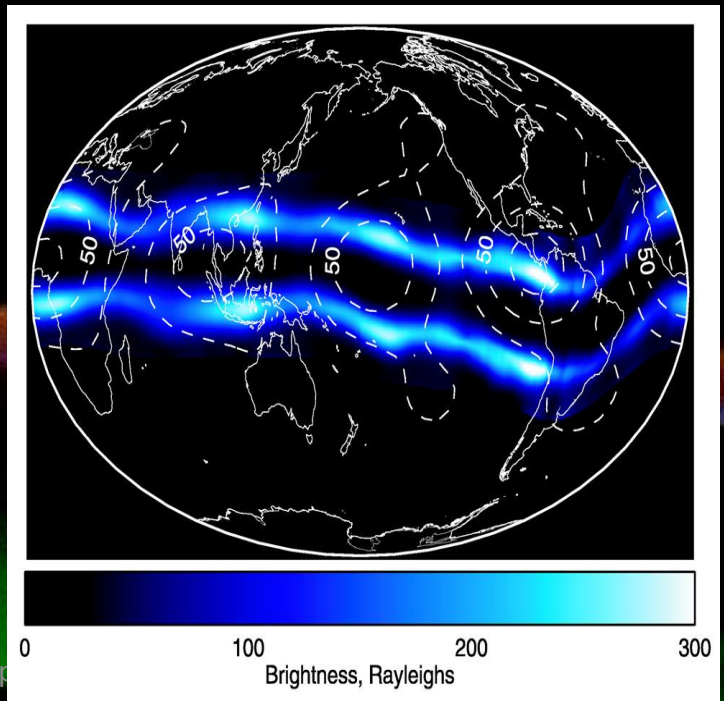
The four peaks in diurnal temperature amplitude result from superposition of the migrating (to the west) tide (DW1) and nonmigrating eastward mode with zonal wavenumber 3 (DE3).

Tides induce variability in the Ionosphere/Thermosphere System

NASA TIMED SABER and TIDI

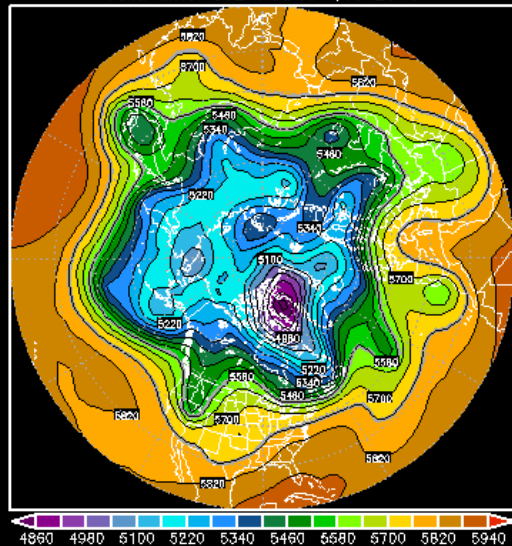


NASA IMAGE

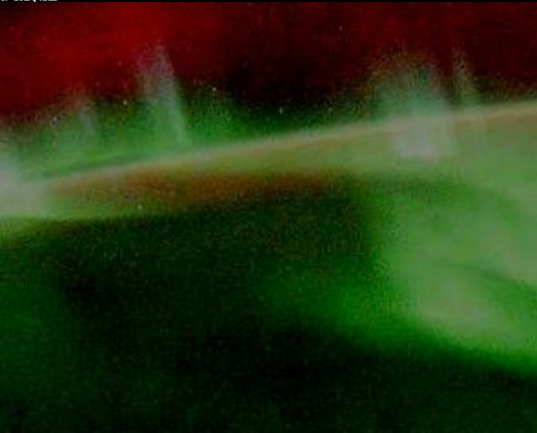


Planetary Waves and the Breakdown of the Polar Vortex

NCEP ENSEMBLE MEAN - 500mb Z (m)
000H Forecast from: 00Z Wed APR,15 2015
Valid time: 00Z Wed APR,15 2015



© OLA/IBIS



The Stratospheric Sudden Warming of January 2013 in GEOS-5

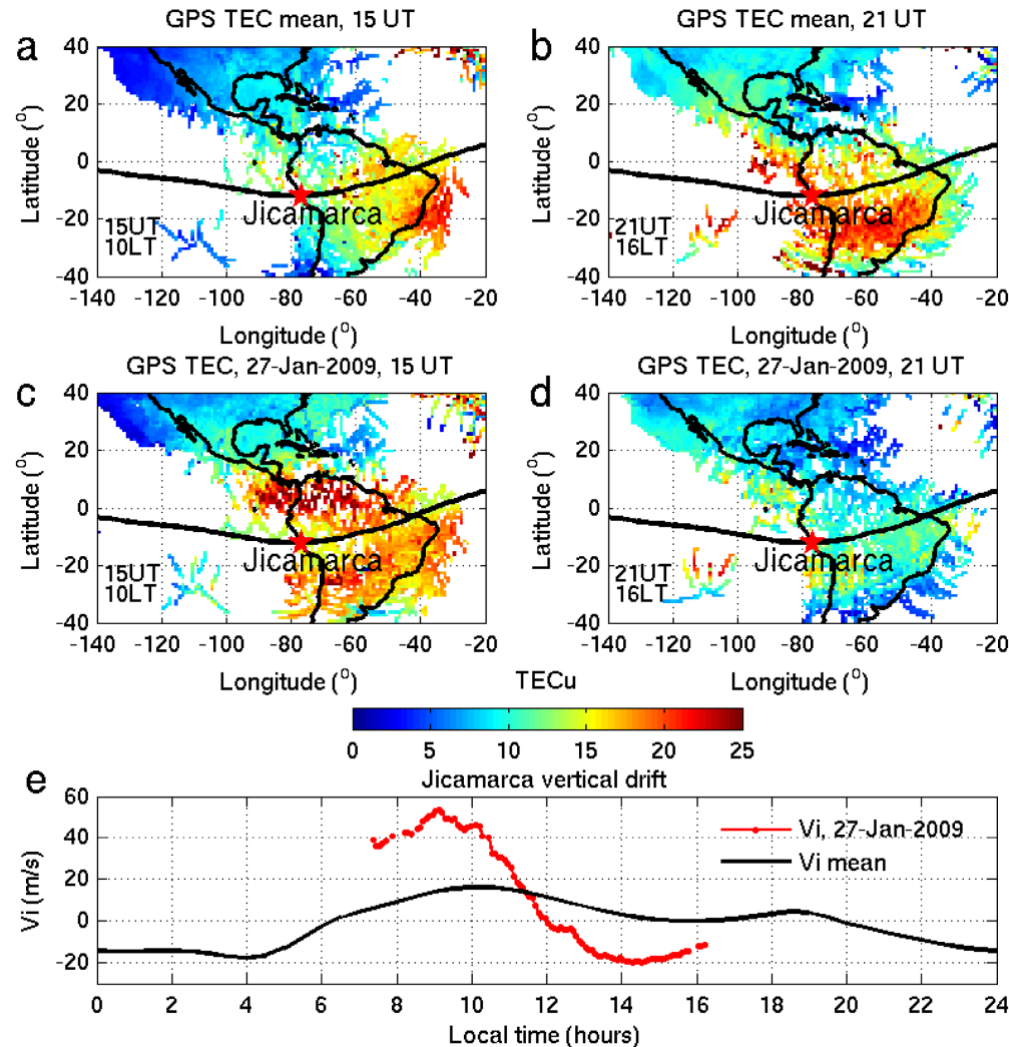
High-Resolution EPV fields at 7hPa (near 35km)

15 Dec 2012 – 28 Jan 2013



Lawrence Coy and Steven Pawson
Global Modeling and Assimilation Office
NASA Goddard Space Flight Center

2009 Strat-warm Impact on Ionosphere and Space Weather



Goncharenko et al. (2010):

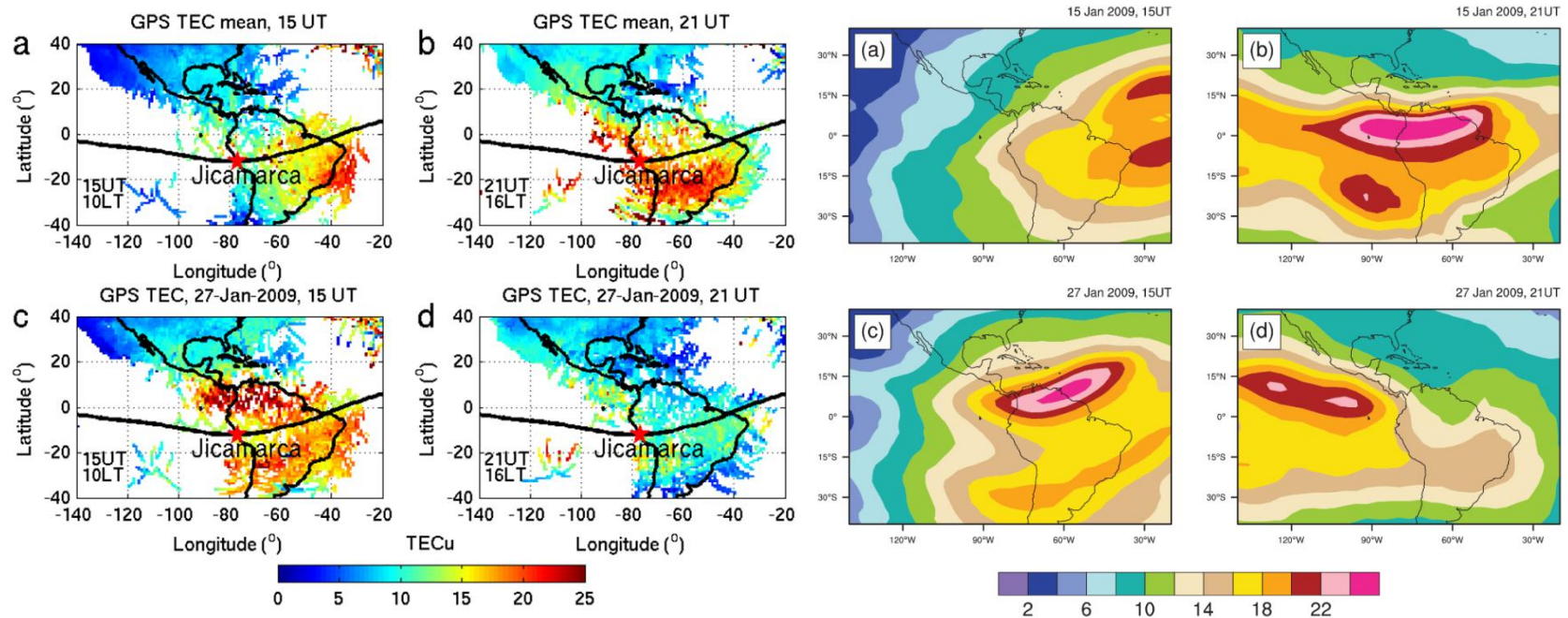
Climatological TEC @ 10 and 16 LT from ground GPS observations.

Same on January 27, after the peak of the warming.

Comparison of plasma drift climatology with observations on Jan. 27.

Does the WAM-IPE Concept Work?

2009 SSW: IDEA TEC forecast



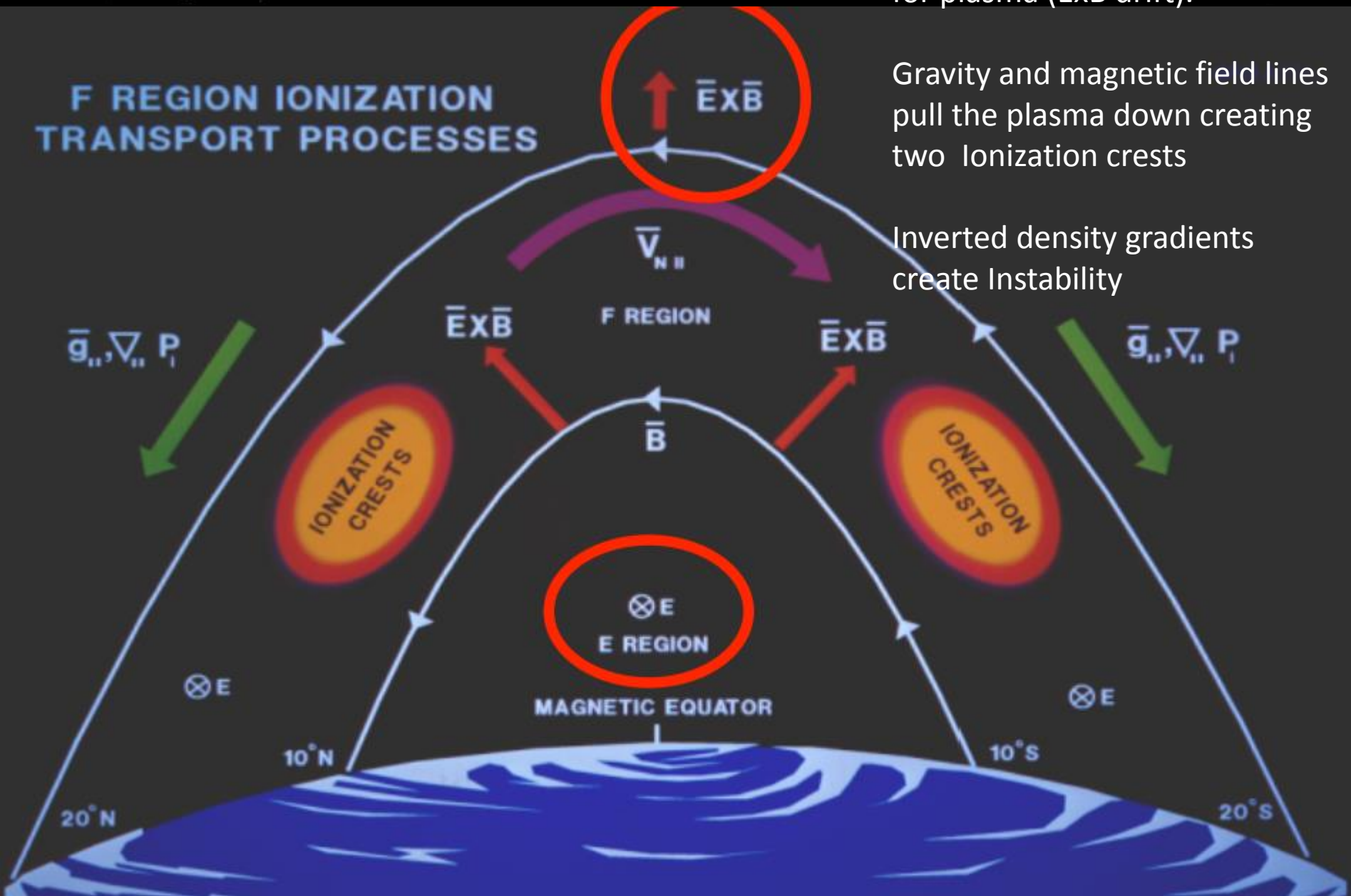
IDEA **14-day** forecast (from Jan 13, 2009) of TEC in the American sector (Wang et al., 2014) vs. observations (Goncharenko et al., 2010).

Equatorial Plasma Bubbles

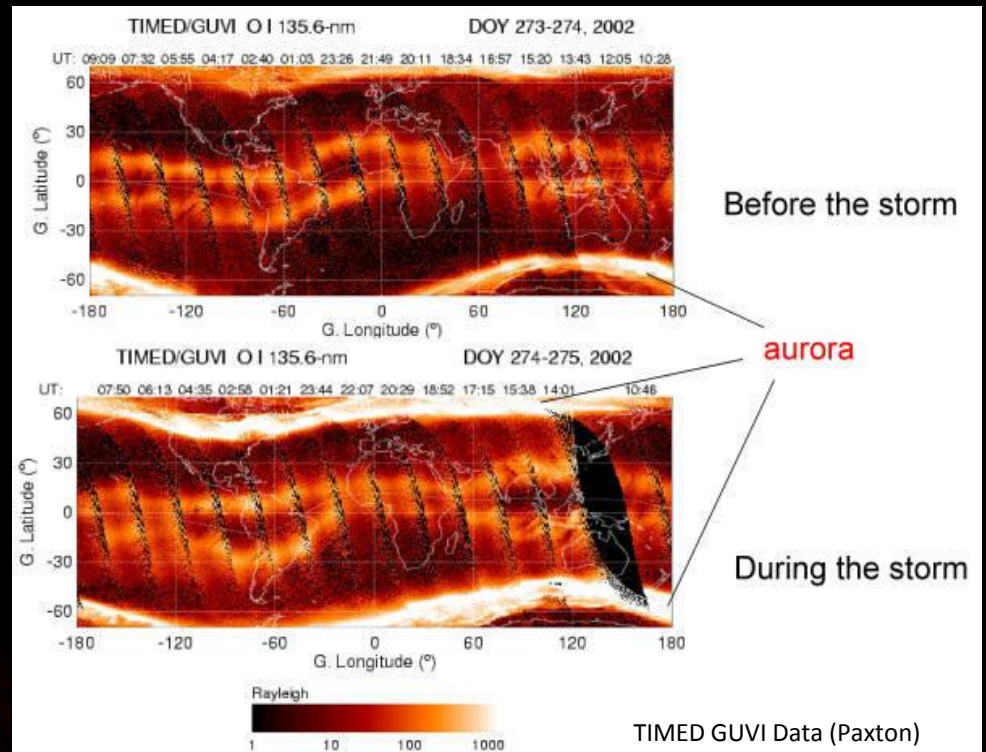
Equatorial electric and magnetic fields create an upward force for plasma ($\bar{E} \times \bar{B}$ drift).

Gravity and magnetic field lines pull the plasma down creating two Ionization crests

Inverted density gradients create Instability

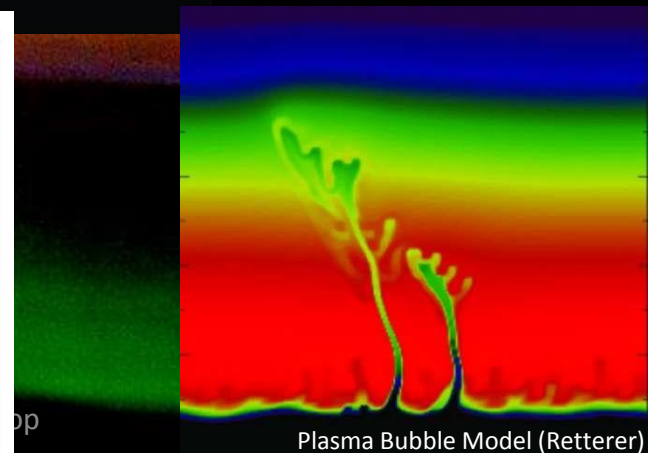
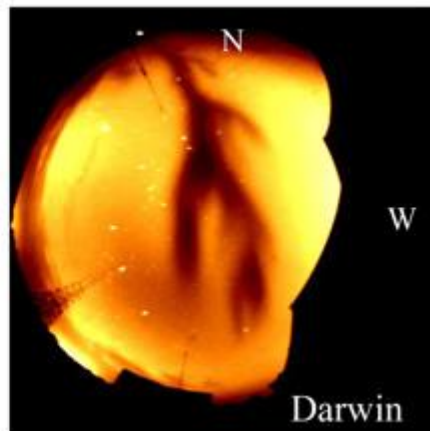
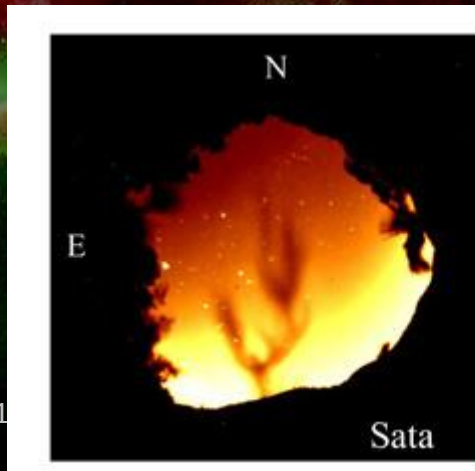
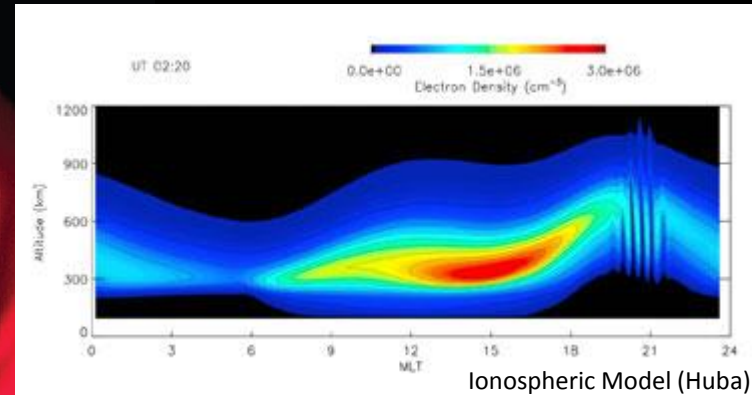
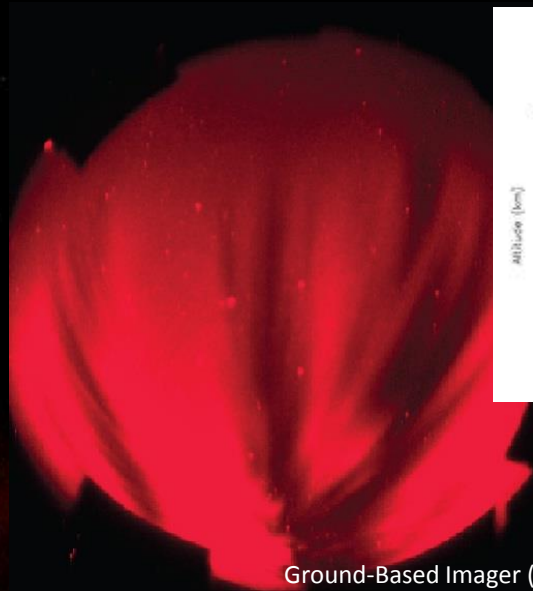
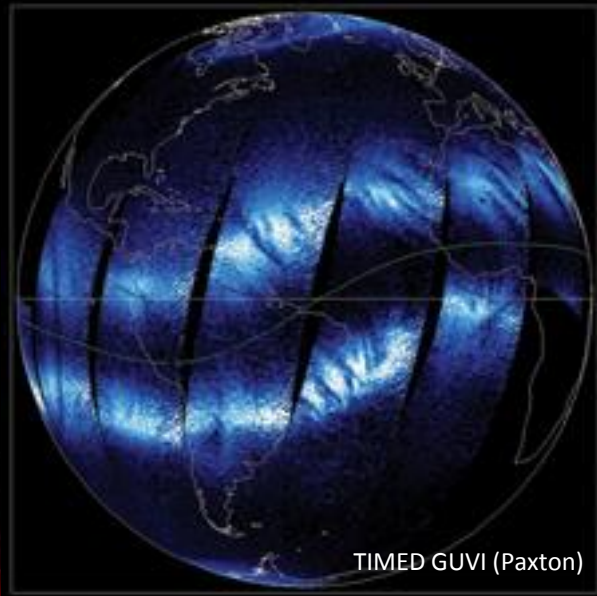


Dynamic Equatorial Plasma



ExB Drift Leads to Plasma Bubbles

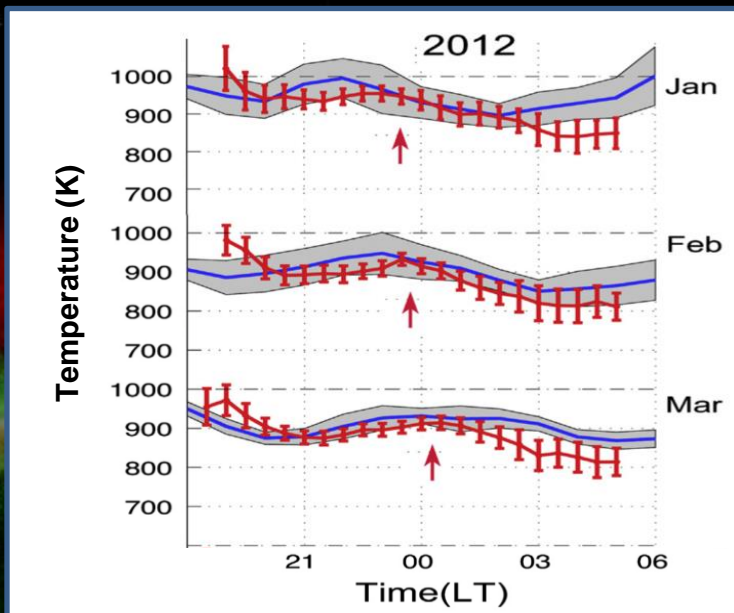
Plasma Bubbles Lead to Dropped GPS Signals



Midnight Temperature Maximum (MTM)

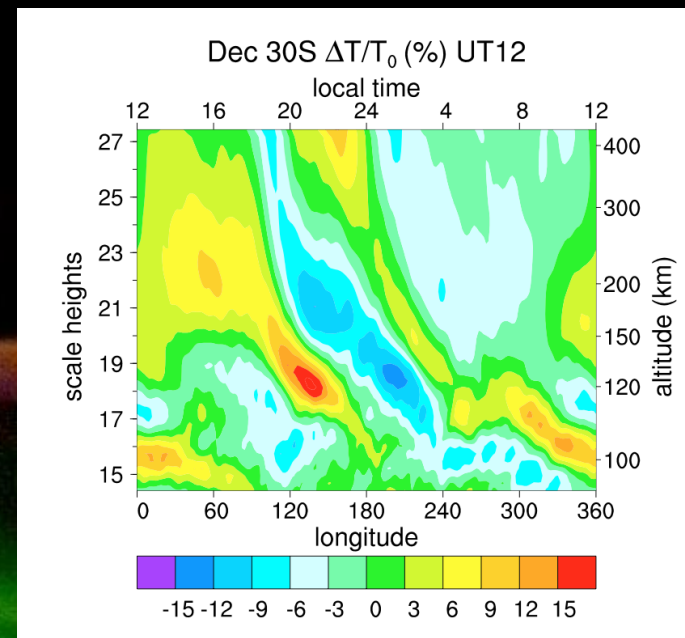
Fang et al 2014

- **WAM can produce the MTM**
- WAM appears to be the first comprehensive model to internally generate an MTM of a realistic magnitude in the thermosphere. Simulation results from the WAM have shown the robust feature of MTM and the associated midnight density maximum (MDM).
- **MTM is the Result of Tides in the Lower Atmosphere:**
- Model results indicate that the feature may be traced down to the lower thermosphere, where it is manifested primarily in the form of an upward propagating terdiurnal tidal wave. Thermospheric tides with higher-order zonal wavenumbers and frequencies can also contribute to the feature.



Meriwether et al. (2013)

Comparisons of WAM MTM (blue) with FPI measurements at Brazil (red) from Sep 2009 to Aug 2012.

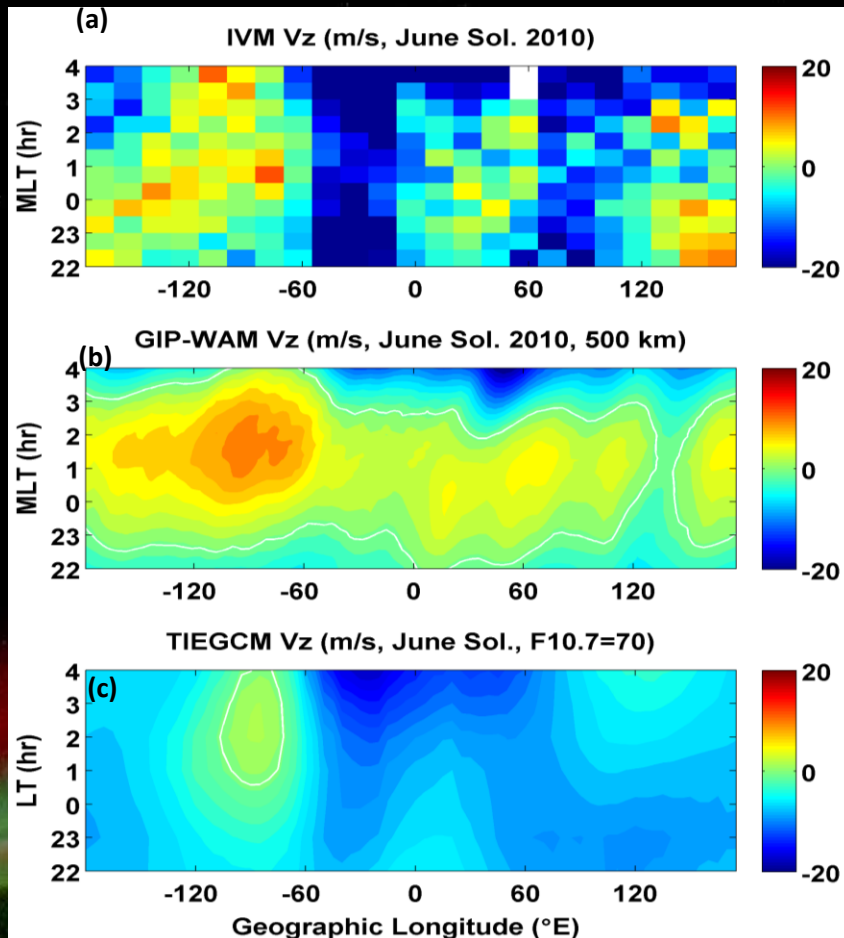


Akmaev et al. (2009)

WAM simulation of relative temperature deviation as a function of height and longitude (local time)

Vertical Ion Drifts from Models and Observation

Fang et al 2014



MTM Produces ExB Drift

The nighttime upward drift is more pronounced in June-July season from the GIP/WAM simulation. For the season, WAM reproduces the magnitude and longitudinal distribution of nighttime upward drift observed by C/NOFS IVM. In contrast, the vertical drift produced by the NCAR TIEGCM shows downward in most longitude except in the American longitude sector.

(a) C/NOFS IVM climatology in 2010
June solstice

(b) WAM-GIP climatology of June and
July 2010

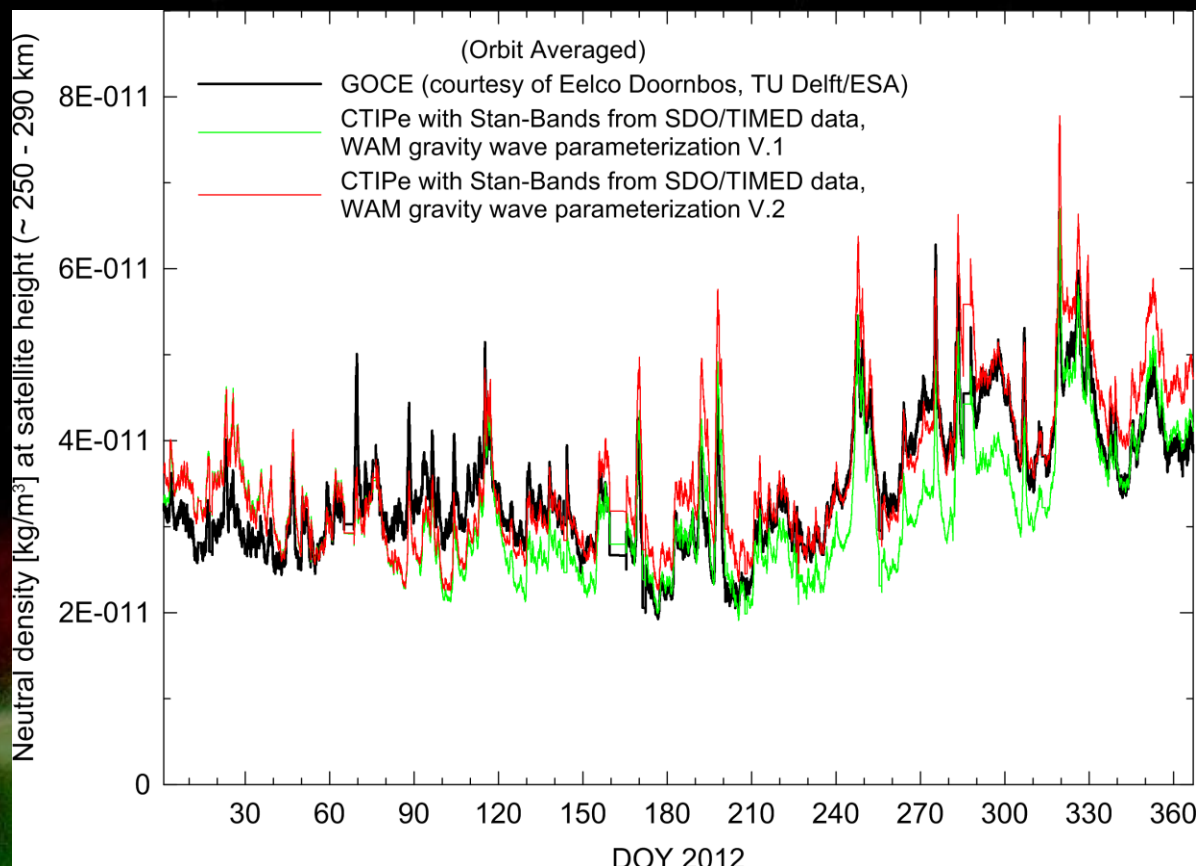
(c) NCAR-TIEGCM results on June
solstice (F10.7=70)

WAM + GIP produces the conditions necessary for post sunset plasma bubbles to form

Improved Satellite Drag Forecasts

Requires better gravity wave forcing

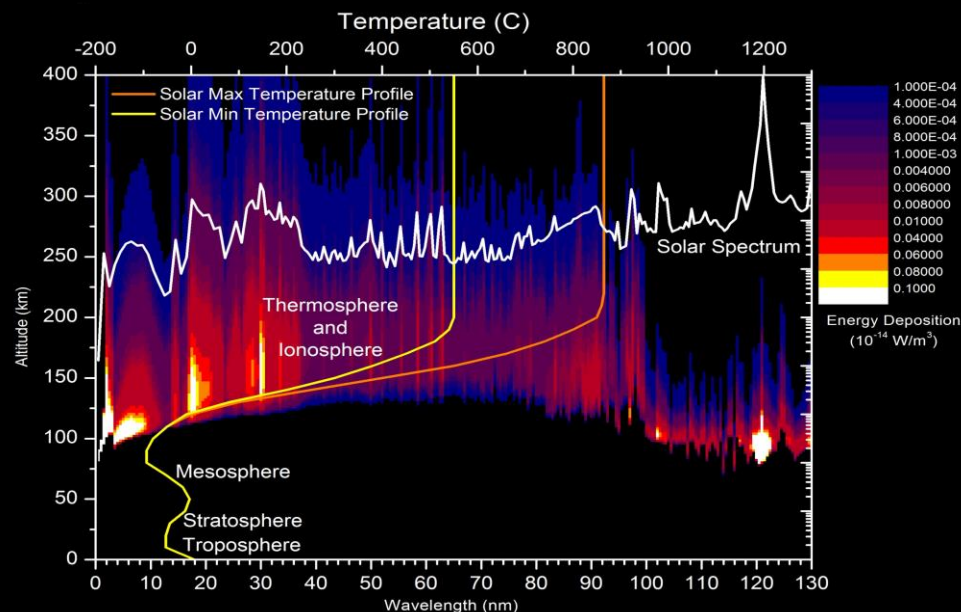
Requires better EUV forcing



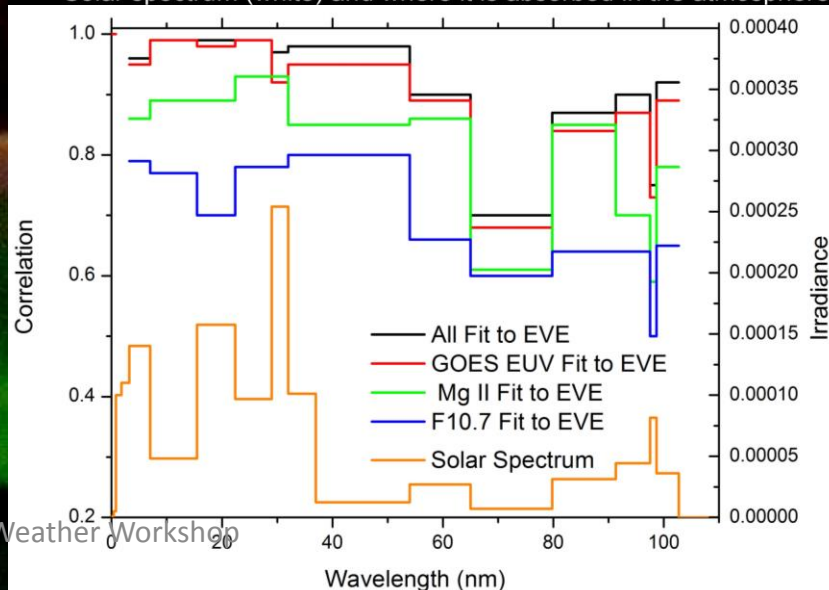
NWS R2O Grant to improve gravity wave parameterization in GFS and WAM (Yudin and Fuller-Rowell)

GOES EUV Irradiance Model Development: Solar EUV Irradiance Specification and Forecast

- **Real-time Proxy model of solar EUV spectrum**
 - Driven by GOES broadband EUV observations
- **3-Day Forecast model of solar EUV irradiance**
 - Driven by forecasts of F10.7
- **7-Day Forecast model of solar EUV irradiance**
 - Driven by ADAPT

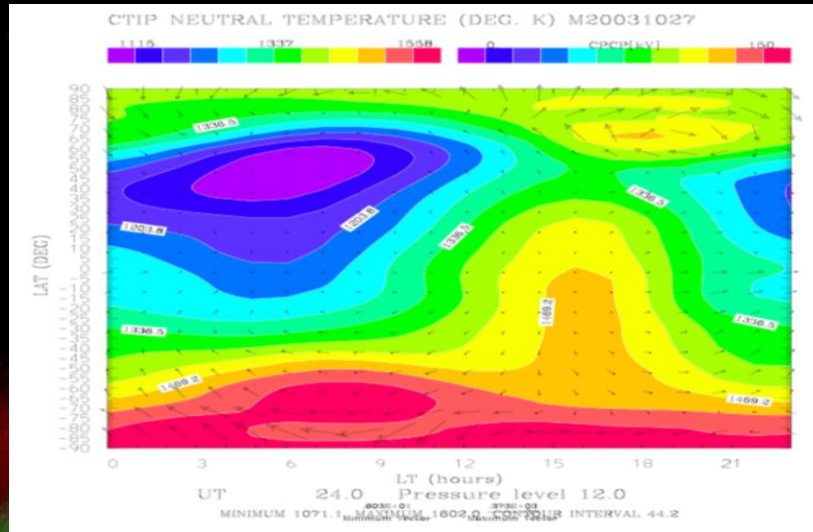


Solar spectrum (white) and where it is absorbed in the atmosphere (colors)

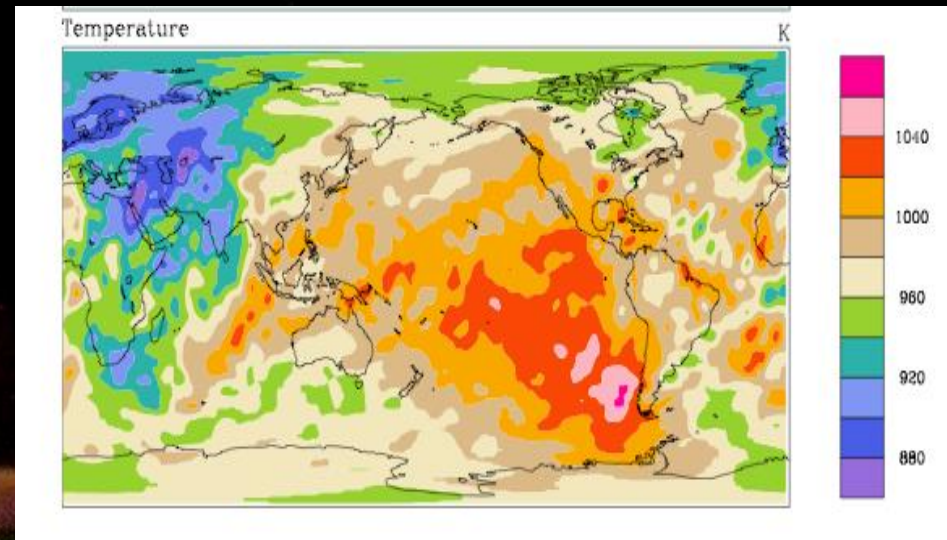


With and Without WAM: Adding the Lower Atmosphere

Typical ionosphere-thermosphere model: Global maps show little fine structure

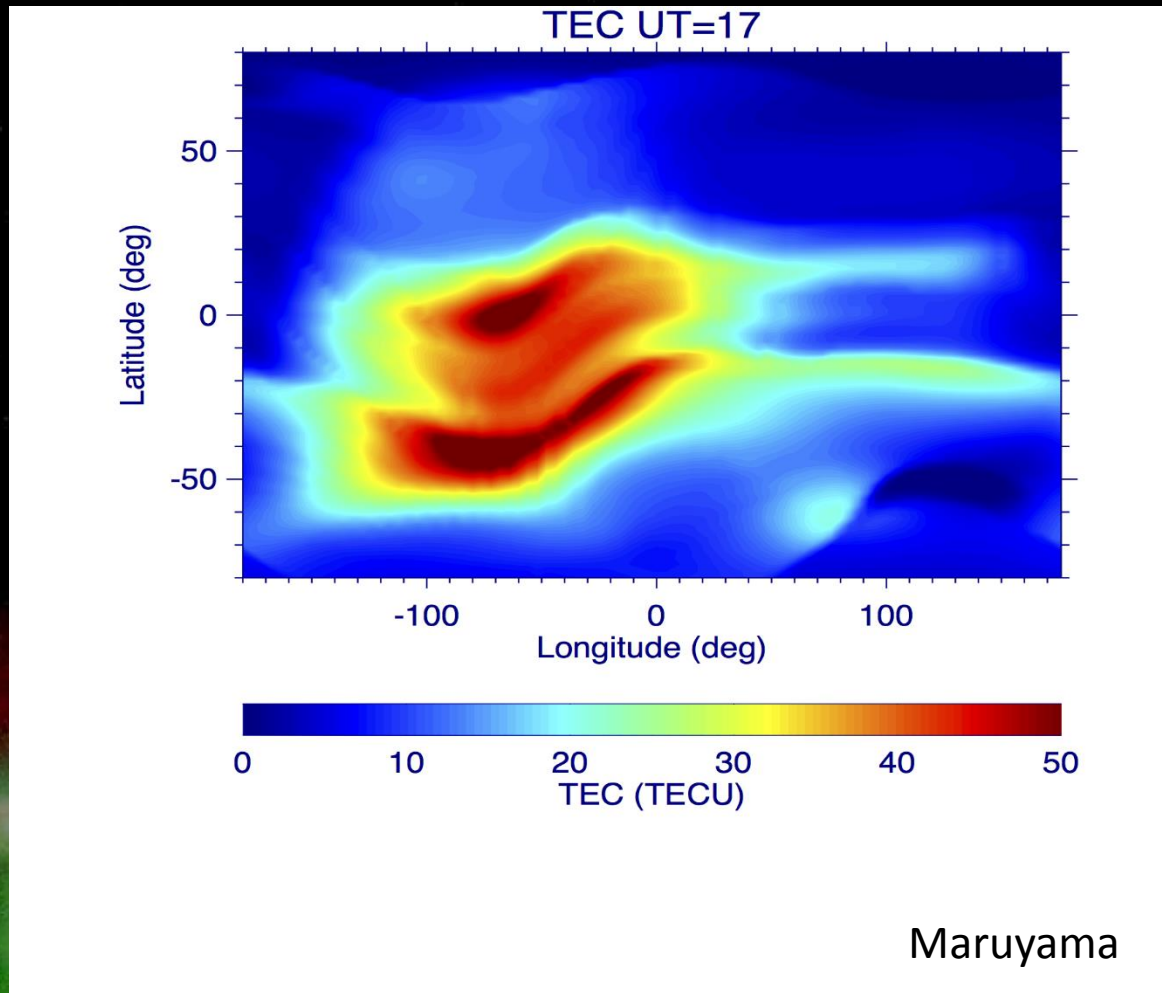


Ionosphere-thermosphere model coupled to the lower atmosphere: Global maps show structure relevant to GPS accuracy and available



The temperature structure from a stand-alone thermosphere ionosphere plasmasphere model (e.g., CTIPe) is similar to the MSIS empirical model. The Whole Atmosphere Model (WAM) drives variability from the chaotic lower atmosphere which introduces a whole spectrum of variability.

IPE Model Results

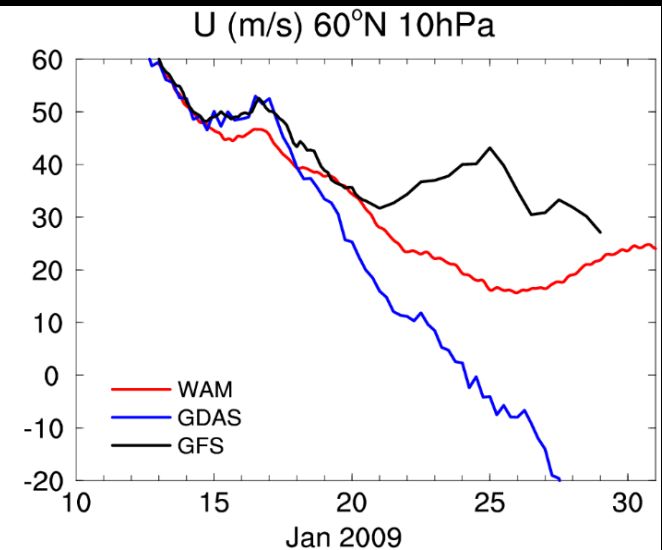
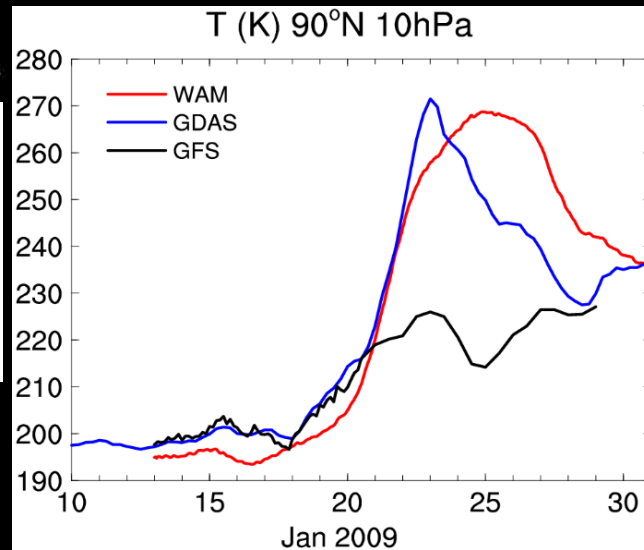


We are currently implementing IPE into the NOAA Environmental Modeling System (NEMS) and coupling IPE to WAM

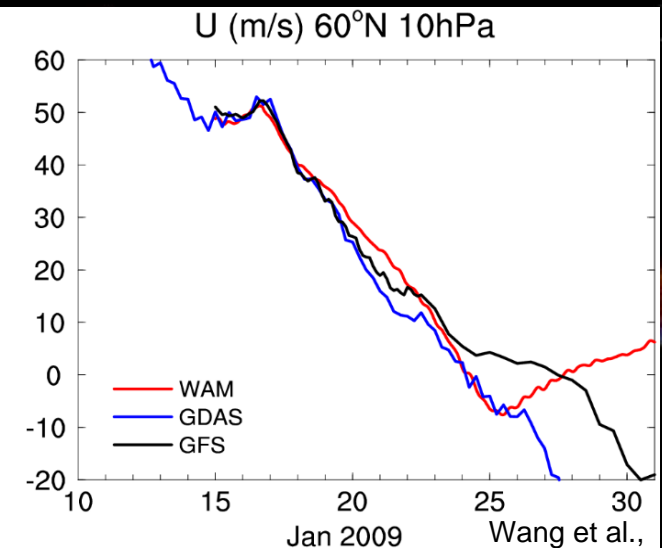
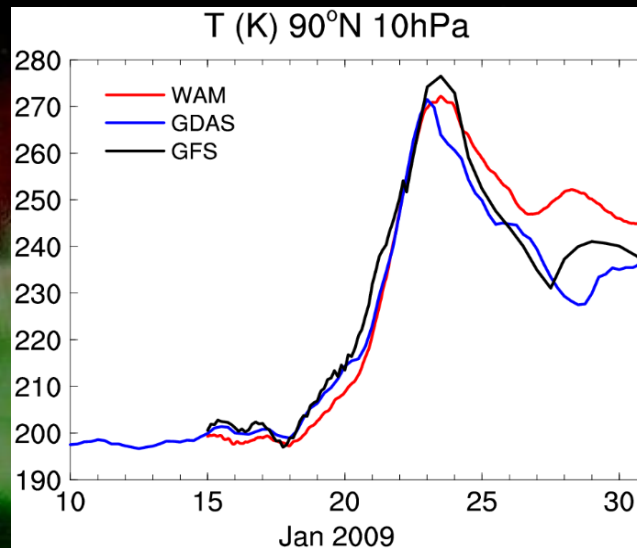
Bonus: WAM and GFS Stratosphere Forecast

WAM Predicts Strat-Warm 2 Days Before GFS

WAM and GFS
forecast from **Jan
13, 2009** of T and U
@ 10 hPa vs GDAS
analysis.



WAM and GFS
forecast from **Jan
15, 2009** of T and
U @ 10 hPa vs
GDAS analysis.



The full impact of WAM on tropospheric forecasts needs to be evaluated

Major Tasks

Blue: Requires collaboration with NCEP/EMC

- Complete WAM Model Development
 - A research parallel run of standalone WAM implemented on WCOSS adopting parallel scripts (FY15).
 - Expand data assimilation to the 60 – 100 km region (FY16).
 - Implement geomagnetic storm drivers and EUV variability into WAM (FY16).
 - Update stratospheric chemistry (O_3 and H_2O) (FY16).
 - Improve gravity wave parameterization (non-orographic GW generation) (FY17).
 - Complete full model testing and validation for all conditions (quiet, geomagnetic storm, climatology, etc..) (FY17)
- Complete the IPE Model Development
 - Complete electrodynamics component (FY15)
 - Incorporate IPE Model into NEMS (FY15)
 - Replace iterative solvers with a direct solver to speed up performance in the multi-processor environment (FY16)
 - Complete full model testing and validation for all conditions (quiet, storm, etc..) (FY17)

Major Tasks (cont.)

Blue: Requires collaboration with NCEP/EMC

Green: Requires collaboration with OAR/GSD/NESII

- Couple WAM and IPE
 - Couple (one-way) WAM and IPE (FY17)
 - Bring real-time space weather data to NCO computers (FY15)
- Medium Range Tasks:
 - Two-way coupling of WAM-IPE (FY19)
 - Develop Ionosphere/Thermosphere (I/T) data assimilation scheme (FY19)
- Longer term tasks
 - Test WAM-IPE at higher spatial resolution
 - Incorporate non-hydrostatic core into WAM
 - Incorporate deep atmosphere gridding concept
 - Quantify WAM vs GFS in tropospheric forecasts

SWPC will require 2-3 additional people to complete the WAM-IPE model development on schedule

Summary:

What Will IDEA Provide?

- The coupled WAM-IPE model system will provide global maps of the ionospheric parameters (specification and forecasts) relevant to customer requirements.
 - Total Electron Content (TEC = height integrated electron density)
 - Rates of change of TEC (spatial and temporal)
 - Single frequency GPS error
 - Scintillation probability for dual frequency (precision) GPS
- Customers
 - Single frequency GPS (airlines, agriculture, shipping, navigation, FEMA, etc...)
 - Dual frequency GPS (mineral/oil exploration, agriculture, navigation, surveying/mapping, DOD, etc...)
 - Satellite communication (satellite operators, NASA, DOD, etc...)
- Medium to long-range forecast of thermospheric density for satellite orbit prediction and collision avoidance.

Questions?